

# X-ray luminous star-forming galaxies

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## Abstract

We present results from the cross-correlation of the spectroscopic atlas of Ho et al. (1995) with the *ROSAT* All-Sky Survey Bright Source Catalogue, in an attempt to understand the X-ray emission mechanisms in nearby galaxies. The resulting sample of 45 galaxies consists predominantly of AGN. However, there are several starforming galaxies spanning a wide range of X-ray luminosities ( $\sim 10^{38} - 10^{42} \text{erg s}^{-1}$ ). We have analyzed *ROSAT* and *ASCA* data for the two most luminous star-forming galaxies, namely NGC3310 and NGC3690. We find that their 0.1-10 keV X-ray spectra can be fitted by a soft thermal plasma of  $kT \sim 0.8$  keV and a harder component with  $kT \sim 10 - 15$  keV or a power-law with  $\Gamma \sim 1.6$ . These are very similar to the spectra of the archetypal star-forming galaxies NGC253 and M82.

**Keywords:** Galaxies: starburst, X-rays, Galaxies individual: NGC3310, NGC3690

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# 1 INTRODUCTION

A large number of faint ( $B < 23$ ) galaxies has been found in deep ROSAT surveys (eg Boyle et al. 1995, Georgantopoulos et al. 1996). These galaxies have high X-ray luminosities ( $L_x > 10^{42}$  erg s $^{-1}$ ) and present narrow emission lines in their optical spectra. Despite the high probability of chance coincidences (ie field galaxies lying accidentally in the error box of the x-ray source), cross-correlations of the X-ray positions with deep optical images have proved the existence of this population at a high level of significance (eg Roche et al. 1995, Almaini et al. 1997). Schmidt et al. (1998) obtained Keck spectra for 50 X-ray sources in the Lockman hole. They find that the large majority of these host an AGN although some fraction of galaxies cannot be excluded.

Now, we have the opportunity to study the properties of such luminous galaxies in the local Universe, using the ROSAT all-sky survey (RASS). Boller et al. (1992) cross-correlated the IRAS Point Source Catalogue with the RASS. Preferential spectroscopic follow-up observations of the highest X-ray luminosity objects (Moran et al. 1997) show that the vast majority of galaxies with  $L_x > 10^{42}$  erg s $^{-1}$  are AGN. Here instead, we have carried out a cross-correlation of the sample of Ho et al. (1996, 1997) and the *ROSAT* All Sky Survey Bright Source Catalogue (RASS-BSC). The spectroscopic sample of Ho et al. contains moderate resolution, high-signal-to-noise spectra of *all* northern galaxies with  $B < 12.5$  providing a complete sample of the galactic activity in the nearby universe. The important advantage of the Ho et al. sample is the pre-existing, very good quality spectra which give us unambiguous

classifications for all the galaxies. The RASS-BSC contains almost 18000 sources found in the all-sky survey carried out during the first years of the ROSAT mission. Our aim is to understand the X-ray emission mechanisms in the nearby galaxies and to test whether a class of X-ray luminous ( $L_x \sim 10^{41-42} \text{ erg s}^{-1}$ ) star-forming galaxies exists.

## 2 THE CROSS-CORRELATION

The results of the cross-correlation are presented in table 1. There are 45 coincidences within 1 arcmin distance from the optical galaxy. On the basis of the sky density of the RASS-BSC sources, we expect less than 1 to be by chance. Columns 1, 2 and 3 contain the names and the coordinates of the objects; the X-ray luminosities calculated using the RASS-BSC count rates and a power-law of  $\Gamma = 2$  are listed in column 4 (we use an  $H_o = 65 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ); finally, in column 5 we give the spectroscopic classifications from Ho et al. (1997). We note that the sample is by no means statistically complete, due to the non-uniform coverage of the sky in the RASS.

From table 1 we see that the large majority of the X-ray galaxies are AGN (Seyferts but also some LINERS). However, there are seven star-forming galaxies while there is also a large fraction (6 galaxies) of late type or normal galaxies. From the seven starforming galaxies of our sample two are well studied dwarf starforming galaxies ( NGC5204, NGC4449) with X-ray luminosities of  $\sim 10^{38} - 10^{39} \text{ ergs}^{-1}$  (Della Ceca, Griffiths & Heckman 1996). The archetypal star-forming galaxy M82

( $7.5 \times 10^{40} \text{erg s}^{-1}$ ) is also in our sample. An interesting finding is the presence of two star-forming galaxies with luminosities above  $10^{41} \text{ergs}^{-1}$  reaching the luminosities of low luminosity AGN. A peculiar object is NGC5905 which although has a very high luminosity of  $1.5 \times 10^{42} \text{ergs}^{-1}$  in the RASS, has shown a significant decline in X-ray flux in subsequent observations (Bade et al. 1996). However, its optical spectrum has not any signatures of AGN activity.

### 3 NGC3690 AND NGC3310

From the starburst galaxies in this sample we present here results on the two most luminous ones, NGC3310 and NGC3690. Both are nearby galaxies at distances of 19.6 Mpc and 63.2 Mpc respectively. Both galaxies appear to be in interacting pairs/mergers. NGC3690 forms an interacting pair with IC694. Their separation is 21'' which translates to  $\sim 6$  kpc at the assumed distance. For NGC3310 there is also strong evidence that it is the remnant of a recent merger, according to anomalies found in its rotation curve (Mulder et al. 1985), and its disturbed morphology (Ballick and Heckman, 1981). Evolutionary synthesis modelling of the optical and infrared spectra of these galaxies has shown that the age of the starburst is about 10Myr (Pastoriza et al. , 1993 and Nakagawa et al. , 1989 for NGC3310 and NGC3690 respectively). Especially in the case of the latter Nakagawa et al. find that the two bursts have different properties, implying either different ages or different Initial Mass Functions (IMF).

### 3.1 X-ray data analysis.

We have obtained the *ROSAT* (PSPC and HRI) and *ASCA* observations of these galaxies from the archive. After following the standard screening procedure, we extracted PSPC and *ASCA* SIS and GIS spectra along with HRI images. The HRI images show that the soft X-ray emission is extended in NGC3310. In NGC3690 the emission comes from three distinct components (the two correspond to the nuclei of NGC3690 and IC694) which again appear to be spatially resolved.

We fitted the *ROSAT* and *ASCA* spectra together. The spectral fitting results are presented in table 2. We found that they are fitted with a optically thin thermal plasma of temperature  $\sim 0.8\text{keV}$  and either a hot thermal plasma ( $kT \sim 10-15\text{keV}$ ), or a power-law with  $\Gamma \sim 1.5 - 1.6$ . The spectral fits for the soft band are suggestive for a thermal origin of the X-ray emission, arising from diffuse hot gas, probably associated with a galactic super-wind (Heckman et al. 1996). However, the origin of the hard X-rays is still unclear as there are more than one possible mechanisms which can produce the observed spectrum. A power-law spectrum can be produced either by X-ray binaries or Inverse Compton scattering of the starburst infrared photons by the supernova generated relativistic electrons, while hot gas (and X-ray binaries) give a thermal plasma spectrum. These results are similar to the results found for the prototypical starburst galaxies M82 and NGC253 (Ptak et al. 1997, Moran and Lehnert 1997), suggesting a common X-ray emission mechanism in star-forming galaxies spanning a wide range of luminosities. Better signal-to-noise ratio and higher energy X-ray spectra but mainly high resolution X-ray imaging are

needed in order to draw any conclusions on the origin of the hard X-ray emission in these galaxies.

## 4 CONCLUSIONS

We have presented our results on the cross-correlation of the sample of Ho et al. (1995) with the RASS-BSC. Our intent was to search for X-ray luminous star-forming galaxies and to probe the X-ray content of the nearby universe. The cross-correlation gives 45 objects within a radius of 1 arcmin. Although this sample is dominated by AGN (mainly Seyferts), there are seven star-forming galaxies spanning a large range of X-ray luminosities ( $\sim 10^{38}$ - $10^{42}$ ergs $^{-1}$ ) rivaling the luminosities of low luminosity AGN. We have analyzed archival observations of the two most luminous star-forming galaxies in our sample namely NGC3690 and NGC3310. We find that their soft spectra are fitted by an optically thin thermal plasma of temperature  $\sim 0.8$ keV. The hard X-ray emission can be fit either with a high temperature thermal plasma ( $kT \sim 10 - 15$  keV) or a flat power-law ( $\Gamma \sim 1.6$ ). These results are similar to those found for the prototypical starburst galaxies M82 and NGC253, suggesting a common X-ray emission mechanism in star-forming galaxies over a large range of luminosities. The combination of AXAF and XMM observations will shed more light on the origin of the hard X-ray emission which currently remains unknown in all star-forming galaxies.

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